STUDY OF THE AVALANCHE TO STREAMER TRANSITION IN GLASS RPC EXCITED BY UV LIGHT.

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Abstract

A small glass RPC filled with Ar/Isob./Freon mixture has been exposed to a UV laser light. Avalanche and streamer regimes of discharge were reached in a fixed region of the RPC exited by the UV. A dependence of avalanche-to-streamer transition process on the laser beam intensity and on the high voltage applied to the RPC was studied. Two types of the streamer signal have been observed. Using a CCD TV camera, pictures on multi-streamer propagation over RPC were obtained.

Introduction

Working voltages for the RPC operated in the avalanche mode is close to values where avalanche transforms into the streamer. If one wants to use RPC in the proportional regime he should be ready to see from time to time the strong streamer signal. At the low threshold of electronics any big pulse is not desirable because it produce a multichannel firing.

An attempt to get better understanding on how streamer grows from the avalanche was done in the present work. A glass RPC with a 2 mm gas gap was exposed to the UV laser beam. The UV laser allow to fix a start point of growth and provide equal conditions for any new avalanche. By variation of the UV light intensity we tried to understand how appearance of the streamer and its characteristics depends on a charge in the avalanche and on the working voltage (HV). Both: induced signal from pick-up electrode and light emitted by discharge in the RPC were registered.

Early a good correspondence between electrically induced signals and a light emission from the glass RPC was found in [1]. The correspondence was observed in following aspects: signal shapes, pulse heights and timing. In [2] one can see pictures of the streamer discharge in the glass RPC taken using

image intensifier and the CCD camera. In [3] was investigated a avalanche to streamer transition and presented pictures of a correspondent process. An estimation of a size of the space propagation of streamer and avalanche discharges was done. It was mentioned about possible mechanism of the discharge in the RPC. In the present work a multi-streamer process were investigated. And laser help as to understand a complex picture of this phenomena.

1 Experimental set-up

Fig.1 shows experimental set-up. A LGI-21 pulse laser was a source of the UV with 337 nm wave length. A duration of the laser pulse was 8 ns with a maximal energy is about 40 μJ. A frequency of light pulses can be changed. Taking into account ~ 1 s recovery time of our RPC when it was operated in the streamer mode we chose the pulse frequency so, that the time between of two discharges in the RPC was bigger than 10 s. Being a source of a high-level noise laser was installed outside of the test room 7 m far from the RPC. The UV beam was focused in a 0.3 mm spot on the entry glass electrode of the RPC by a long-focus spherical mirror (SM).

At first stage of the present work two photomultipliers (PM1, PM2) were used for monitoring of the laser beam intensity and for to measure spectrum of the light from discharges in the RPC. One of photomultipliers, PM1, was faced to the spherical mirror. This one with UV filter was used to measure part of the light scattered off SM because of mirror imperfection and thus for monitoring of a laser intensity. The second photomultiplier, PM2, faced to the RPC was used for a light registration from discharges occurring in the gas. By changing of optical filters between PM2 and RPC it was possible to measure different ranges of a discharge light spectrum. Signals from both photomultipliers were fed to QDCs.

RPC and PMs were housed in a light shielded box as it is shown in fig.1. The laser UV entered this box through a window made of glass filter transparent for UV only. The laser beam intensity (I) was changed by installation of grey optical filters between the laser and the shielded box entry window.

At the final stage of the work, second photomultiplier (PM2) was replaced with a image intensifier and TV CCD camera to get picture of a streamer discharge distribution over the RPC area.

Our $10 \times 10\ cm^2$ RPC with a 2 mm gas gap was made of 2 mm glass plates. A bulk resistivity of glass was found to be $\sim 5 \times 10^{12} \Omega \cdot cm$. A high voltage cathode was performed by metalization of the glass plate surface. A transparency for the visible light of the thin metallic layer was about 70%. A 2 mm in diameter area in the center of the cathode was free of metalization. The UV beam entered the RPC through this area.

An anode electrode was done with a layer of a carbon paint on the glass surface. And $2 \times 2\ mm$ free of paint area was in the center of the anode to the UV light can leave the RPC without producing a scintillation.

An induced signal from the anode was amplified by a U33 amplifier having a gain=20 and 400 MHz bandwidth. RPC signal and signals from photomultipliers were digitized with a 11-bits P267 module ("SUMMA" standard). The input sensitivity of the P267 is $\sim 0.3\ pC/count$. When it was necessary to estimate the RPC efficiency, a discriminator with the 6 mV threshold was used after the amplifier.

In the our study we felt RPC with $Ar/iso - C_4H_{10}/CF_3Br$: 54/36/10 mixture. A composition like this was in use for the beginning of RPC development and allow as to obtain a rich picture of the streamer process.

2 Experimental results

A first part of this section presents a behavior of induced charges in the avalanche to streamer transition region. The second subsection shows the data on a spectrum of the streamer light coming from the RPC. Examples of optical images are in the third part.

2.1 Avalanche to streamer transition

First of all, we had looked how efficiency (ϵ) of the RPC excitement depends on the laser pulse intensity (I). Fig.2 shows ϵ versus I/I_0, where I_0 is the maximal intensity what we could get with the LGI-21. This result was obtained with the voltage, $HV = 7.8\ kV$, at which no streamer signal was observed when our RPC was tested on a cosmic. As fig.2 demonstrates that a reply from the RPC is always seen at $I/I_0 > 0.2$. Below this intensity not every UV pulse produce the discharge. Only one of $\sim 10^3$ pulses evokes discharge at $I/I_0 \leq 0.05$. We think that at this low intensity, $\sim 5\%$ of I_0,

UV light occasionally knocks out no more than one electron from cathode. This assumption based on a observation of almost 100% efficiency for the our chamber on the cosmic when avalanche could start from a one primary ionization cluster. Tests with low intensity are called here as a work in "one electron" mode.

A mean value of the induced charge ($< Q >$) was measured in the "one electron" mode and is shown in fig.3a as a function of the high voltage. A behavior of $< Q >$ in fig.3a looks like what we saw with this gas mixture in cosmic tests: the avalanche signal rising from 0.05 pC to ~ 1 pC with the HV growth from 7.5 kV to ~ 8.2 kV and becomes to be accompanied by the strong streamer signal (~ 100 pC) at $HV > 8.1 - 8.2$ kV. A fraction of the streamer at different HV is given in fig.3b. The avalanche signal caused by the laser beam has a less variation in the amplitude than the charged particle does. It is so because the avalanche growth always starts by the electron knocked out from the cathode and no variation in the primary charge position along the gas gap as it is for the case of crossing particle. That is why the avalanche signal can be easily separated from the noise (pedestal) even at $< Q > \approx 0.05$ pC. A behavior of the streamer induced signal in the "one electron" mode looks like a set of pulses (sparks) following in time one by one. The delay between the avalanche signal and the first streamer pulse can be up to 100 ns. Below we call this type of the streamer as a "streamer-A".

It was interesting for us to see how the induced signal changes if to increase a number of knocked out primary electrons. Fig.4a shows the $< Q >$ as a function of the ratio I/I_0. A measurement was carried out at the $HV = 7.8$ kV. The avalanche charge ($< Q_a >$, boxes) rises with a growth of the UV intensity. When the $< Q_a >$ reaches about 1 pC the streamer signal (triangles) appear. However, this streamer signal differs from the "streamer-A" observed at more high HV in the "one electron" mode. This new streamer consists of only one pulse with the charge of 30 pC. Its amplitude spectrum is rather narrow. The distribution width is few pC only. This streamer follows the initial avalanche with the few ns delay and its duration is $7 - 10$ ns(FWHM). We call this streamer as a "streamer-B". In the range of $I/I_0 = 0.2 - 1$ no considerable variation in the "streamer-B" charge was found. Fraction of the "streamer-B" at the different HV is presented in fig.4b.

At the next step we looked for signals from the RPC at the maximal

intensity of the UV beam. Fig.5 gives a mean induced charge as a function of the HV when the I/I_0 was ≈ 1. Below 7.4 kV only avalanche signal was observed. The mean avalanche charge is shown in the figure with circles. As fig.5 show at 7.4 kV the streamer signal (boxes) with a $< Q_s >= 15$ pC appears. This streamer signal is the "streamer-B": it consists of only one narrow (FWHM$\approx$ 10 ns) pulse. The variation in its amplitude is about $10 - 15\%$. The time between the "streamer-B" and the avalanche signal is few ns. The amplitude of the "streamer-B" rises slowly with HV from 15 pC to about ~ 30 pC. A probability to observe "streamer-B" at different HV is shown in fig.6 (boxes). At voltages of $7.8 - 8.3$ kV "streamer-B" is only signal what we could see. Starting from $HV \sim 8.3$ kV both "streamer-B" and "streamer-A" (triangles) can be observed. Fraction of the "streamer-A" rises with HV as it is shown in fig.6 (triangles). A presence of the "streamer-A" can be noticed by eye through the RPC glass wall: it looks like a set of sparks near the point where light enters the RPC. Some of sparks are few cm far from this point.

2.2 Light coming from discharges

A light coming from discharges through the glass electrode was measured with a photomultiplier "FEU-87". To estimate a spectrum of the discharge light a set of measurements was carried out with five different optical filters (BS8, JS4, JS12, JS18 and OS13), installed between the RPC and photocathode. A transparency of these filters at different wave length is given in fig.7.

From the beginning we should say that attempts to measure light from the avalanche were failed. The avalanche light is rather week. It is at level of a background light. The background light appear due to reemission by the glass (and by the dust on the glass surface) during few ten ns after UV pulse. As for the streamer a good proportionality between the RPC induced charge and the number of photoelectrons ($N_{p.e.}$) was observed. The value of $N_{p.e.}$ as a function of the $< Q >$ is given in fig.8. The data in this figure were obtained without any optical filter between the RPC and PM. The figure demonstrates a good proportionality between induced charge and light output. A linear approximation of the data brings a scale value of $\sim 1.59 \pm 0.02$ $p.e./pC$. By the same way, $N_{p.e.}$ versus $< Q >$ was gotten for cases when PM was added with five filters mentioned above. Scales found after approximation with a

linear law are presented in the following table for the each filter.

filter	BS8	JS4	JS12	JS18	OS13
$N_{p.e.}/pC$	1.56 ± 0.04	1.46 ± 0.02	0.94 ± 0.02	0.55 ± 0.01	0.12 ± 0.002

The table gives a possibility to reconstruct the spectrum of the streamer light coming through the glass cathode in $\lambda \approx 300-600\ nm$ range. Corrected for the FEU-87 sensitivity characteristic this spectrum is shown in fig.9. As can be seen the spectrum fast decrease as the λ decrease from $\sim 500\ nm$. It could be result of the light absorption in the window glass for the $\lambda \leq 500\ nm$. A range of registered wavelengths correspond to the photon energy of $2-4\ eV$.

2.3 Images of the streamer discharge

As was said above the streamer looks by eye through the glass electrode as one or several bright spots.

To get images of discharges we used the same glass RPC as it was in measurements of the light spectrum. The RPC was viewed with Image Intensifier (II) "KANAL" having bialkali photocathode. A high voltage pulse sent to a microchannel plate inside "KANAL" open the Image Intensifier.

A output screen of the II was viewed with the CCD camera. A self-made card inside the IBM PC was used to digitize output signals from the CCD camera. Images were recorded into files. Furthermore, images were observed during the data taking on a computer monitor.

It was found that the streamer looks through the glass window like one or several bright spots. The diameter of each spot is about 2 mm. Fig.10 supports a idea that a correlation between the 'optical' and 'electrical' information exists. This figure show a number of bright spots (N_s) observed through the glass as a function of the induced charge. A good enough proportionality between the N_s and charge can be seen in the figure.

As examples showing how the streamer develops in the space, figure 11 presents two pictures obtained with the II and CCD camera. A real size of the each image is $3.5 \times 5.5\ cm^2$. A spot position, which is the most close to the center of the picture, corresponds to the place where UV beam crossed the RPC. Pictures were obtained for the "streamer-A" process.

3 Conclusions

The excitement of the glass RPC by the UV pulse laser provided with interesting information on how the avalanche transforms into the streamer. Two types of the streamer have been observed. One of them, "streamer-B", is produced by the field of the primary avalanche - it appears when the avalanche charge (exactly say, induced charge) reaches $\sim 1\ pC$ and it weakly depends on the initial electric field in the wide range of HV. The "streamer-B" follows the avalanche discharge with few ns delay only.

The second type of streamer, "streamer-A", appears when HV exceeds some value. For our gas mixture it was at $HV > 8.2\ kV$. Appearance of the "streamer-A" does not depend on the primary electrons number. By eye, this streamer looks like several sparks round point where the laser light enters the RPC. Some of sparks are few cm far from the primary point. As it was said in [3] it seems this kind of process in the RPC is connected with a secondary photon emission from primary discharge. Secondary discharges should start from photoelectrons knocked out from cathode by photons from a short wavelength tail of the emission spectrum. Because there is weak electric field around the primary discharge the secondary discharge can start only at some distance from initial.

The estimations of the streamer light spectrum and intensity of the light from discharges in the RPC have been done. We hope these data can be useful in the future for everybody who will try to reconstruct a space-time picture of processes in the RPC by use the optical information.

References

[1] Y.Inoue, et.al., NIM A394(1997)65-73

[2] I.Kitayama, et.al., NIM A424(1999)474-482

[3] A. Semak, et al., NIM A456 (2000) 50-54

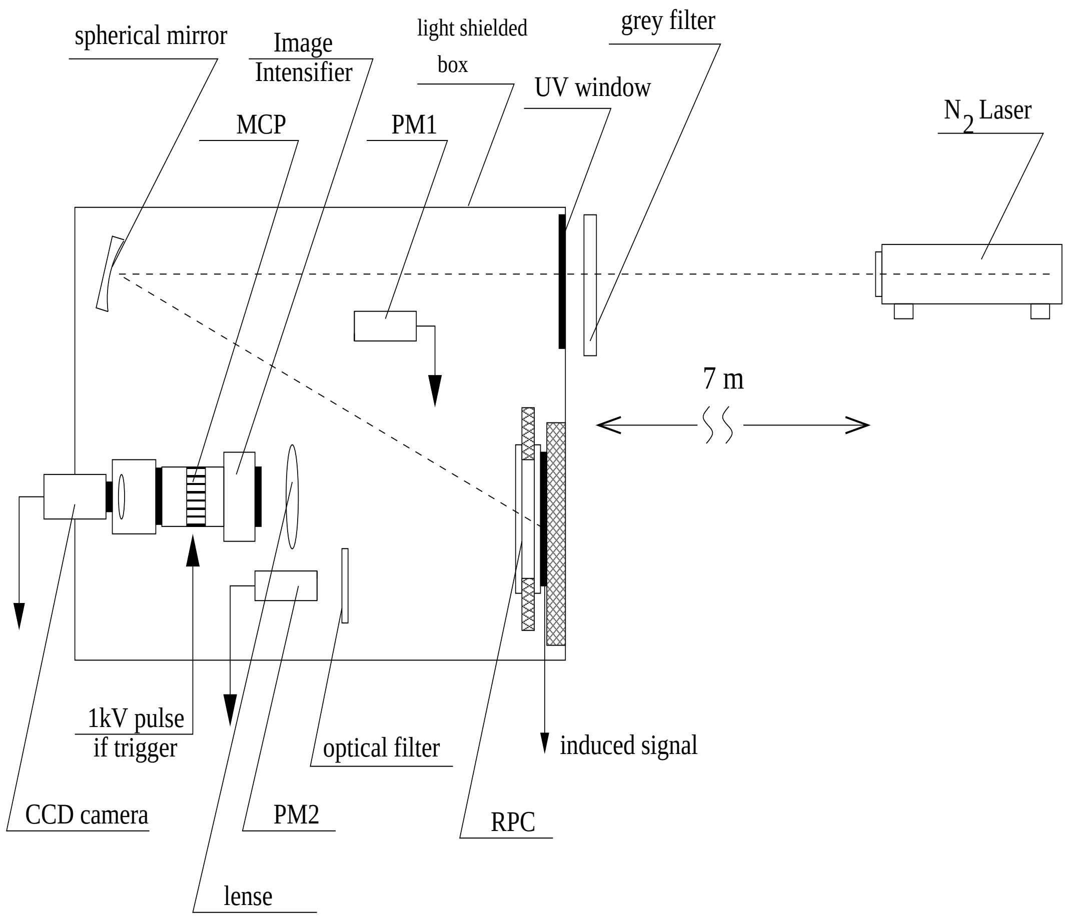

Figure 1: Experimental Set-up.

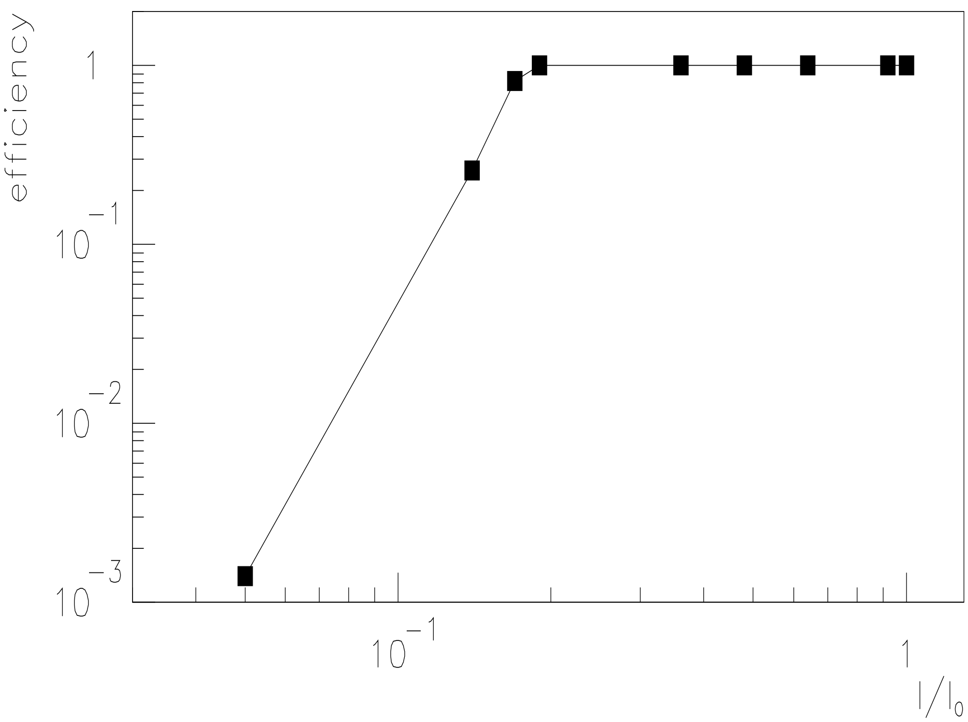

Figure 2: Probability to get the RPC reply at different intensities of the laser pulse. $HV = 7.8\ kV$.

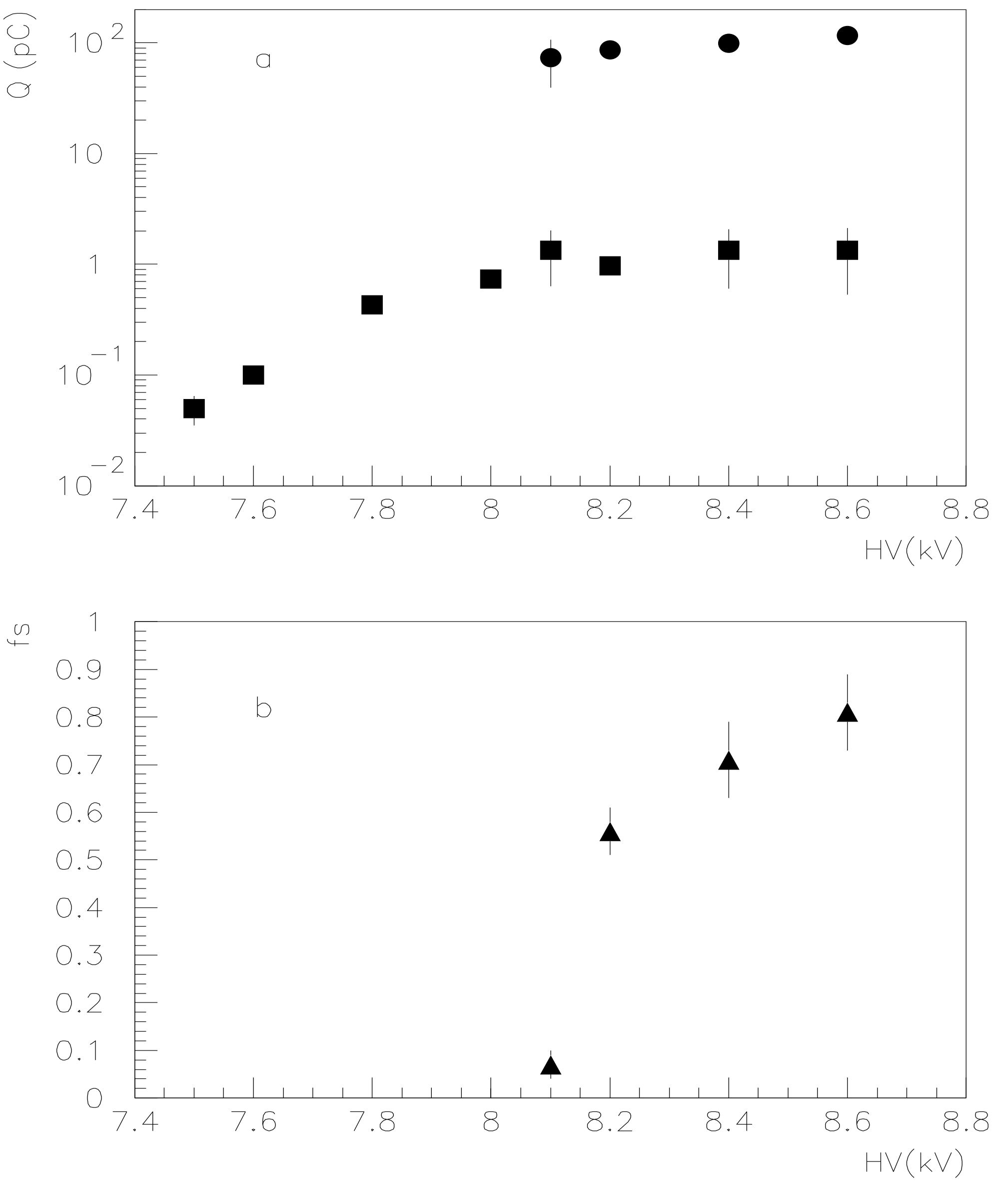

Figure 3: Measured at different high voltages: a - mean charge of the avalanche (boxes) and streamer (circles), b - fraction of the 'streamer-A' signal. The data was obtained in the "one electron" mode.

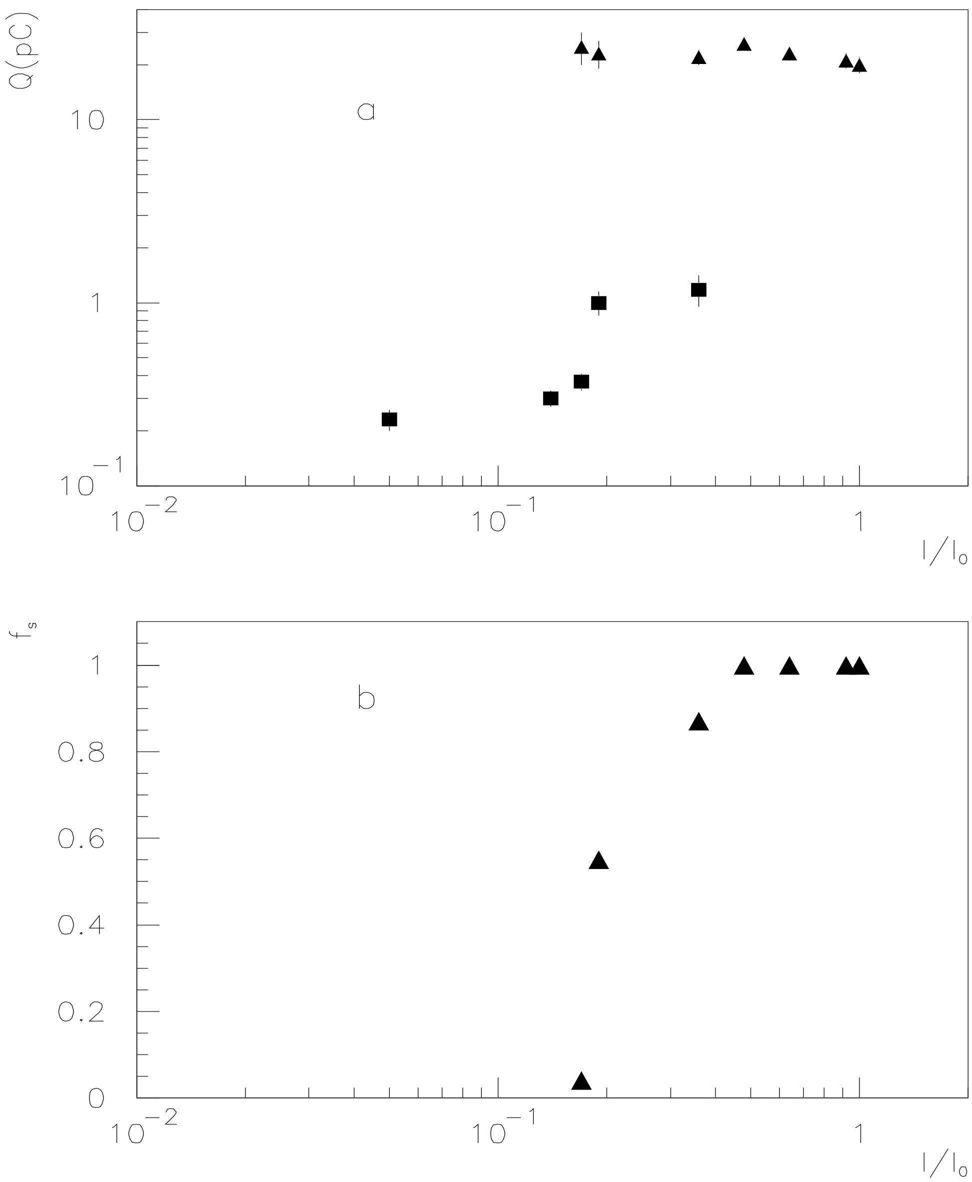

Figure 4: A top picture shows charges of the avalanche (boxes) and "streamer-B" (triangles) as a function of the light intensity. The fraction of the "streamer-B" at different I/I_0 is given in the bottom picture. The data was obtained at HV=7.8 kV.

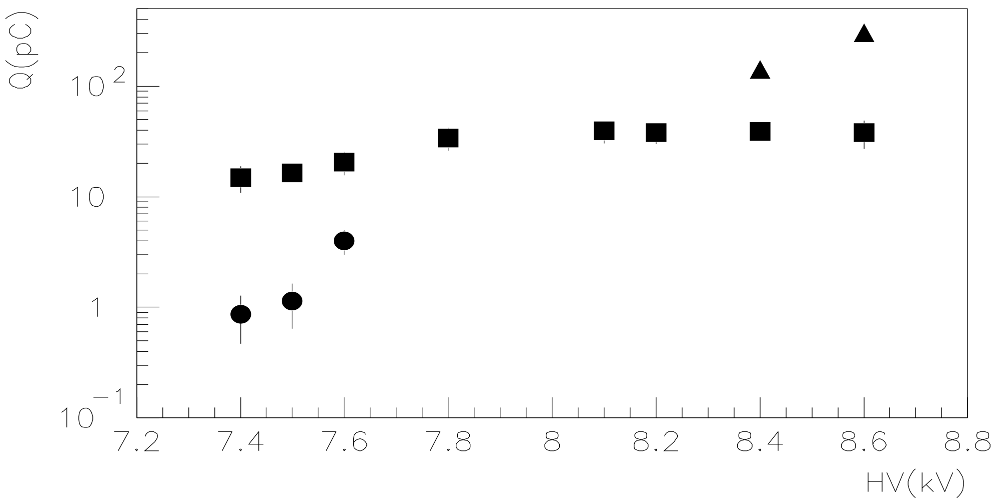

Figure 5: Three types of the signal observed at different HV. The intensity of the light $I/I_0 \approx 1$. The avalanche charge is given with circles, the "streamer-A" is shown with triangles, black boxes describe the "streamer-B".

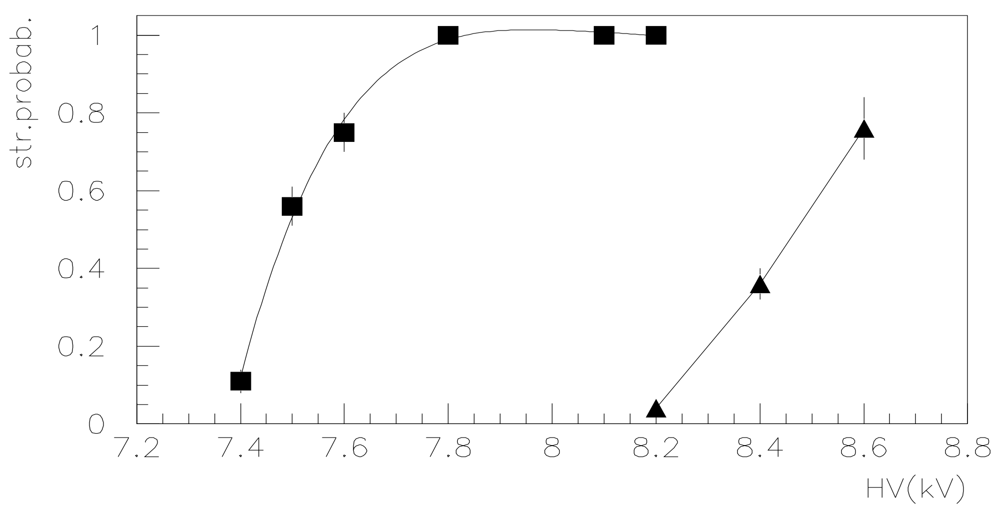

Figure 6: A probability of the "streamer-A" (triangles) and "streamer-B" (boxes) at different HV. The UV light intensity is maximal.

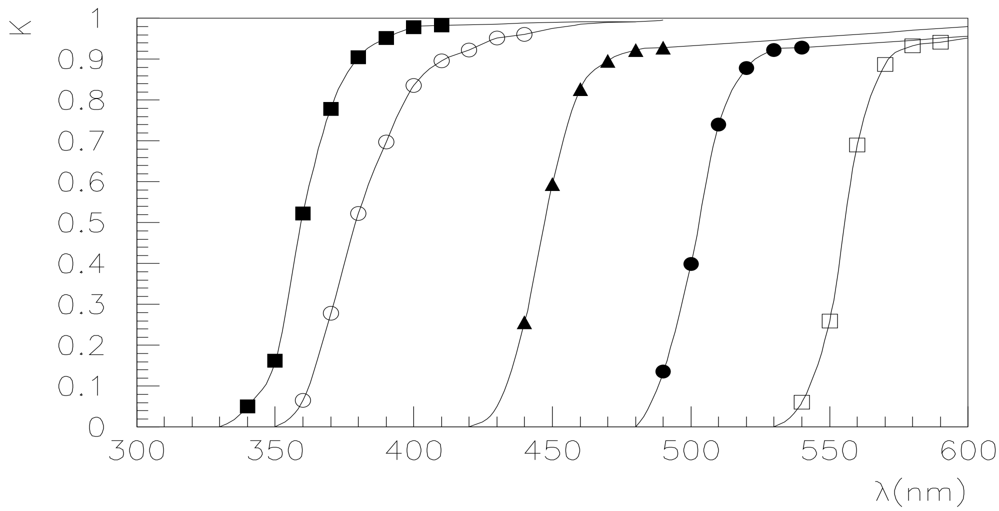

Figure 7: A transparancy as a function of the wavelength for five optical filters: BS8(black boxes), JS4(sweet circles), JS12(triangles), JS18(black circles), OS13(sweet boxes). Curves are taken from specifications given by manufacturer of filters.

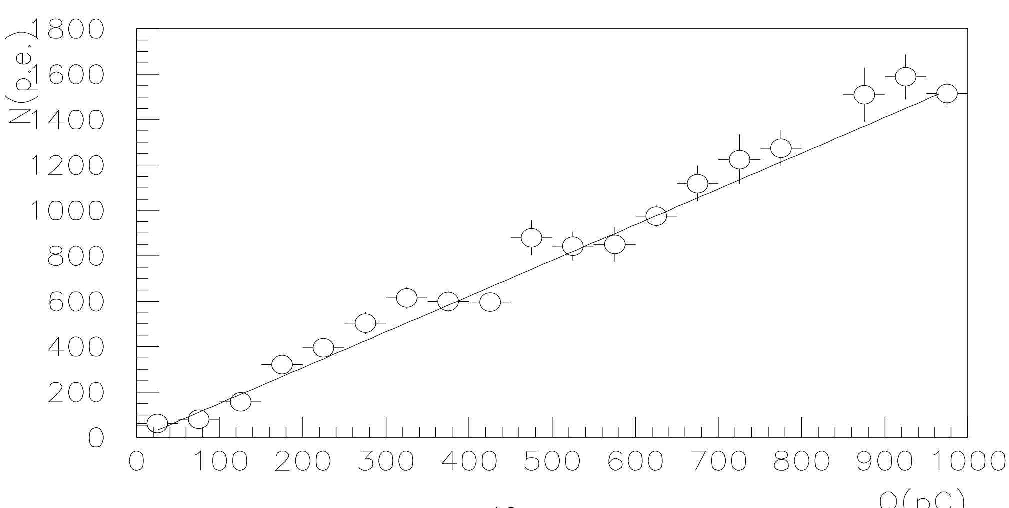

Figure 8: The number of photoelectrons (light from the streamer) as a function of the induced charge. There is no filter between PM and RPC. A line shows the result of the fit by linear law.

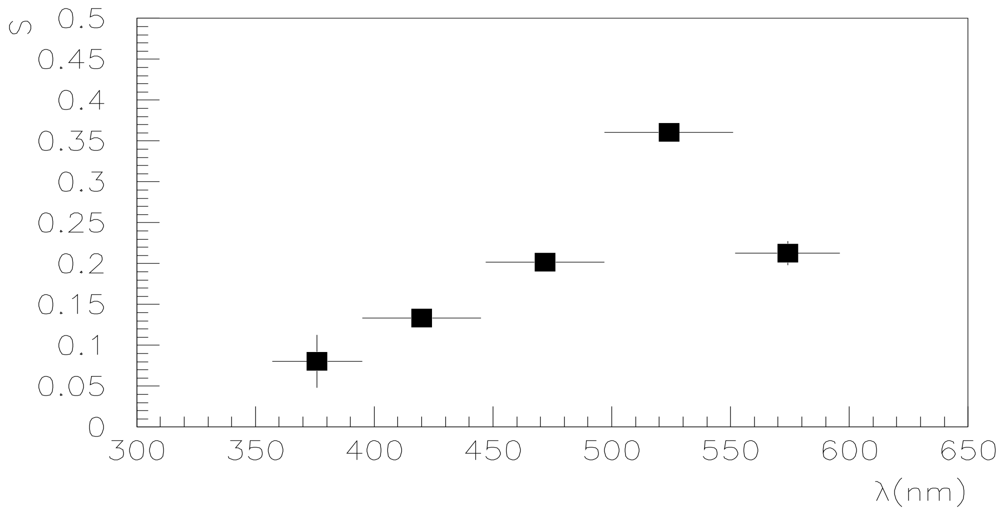

Figure 9: A reconstructed spectrum of the streamer light. It is normalized by unit.

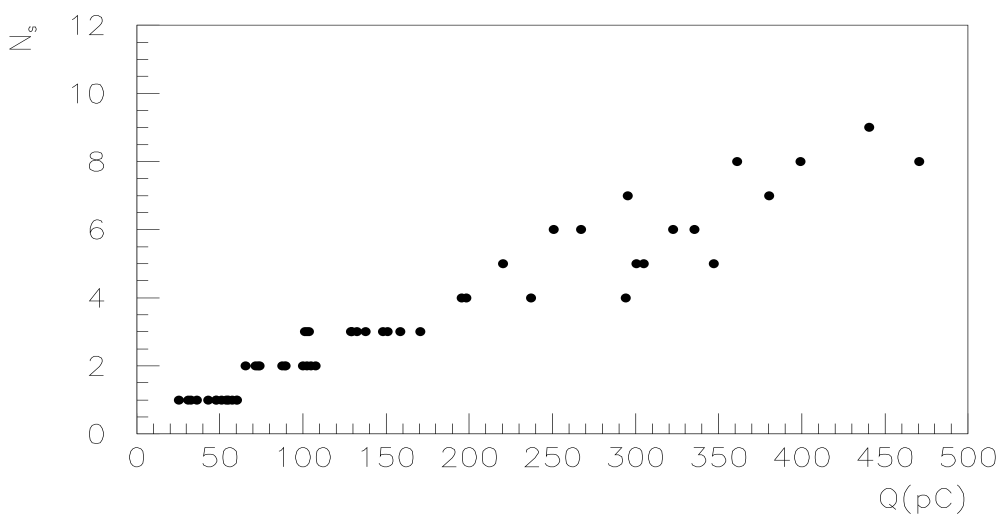

Figure 10: A number of light spots as a function of the induced charge.

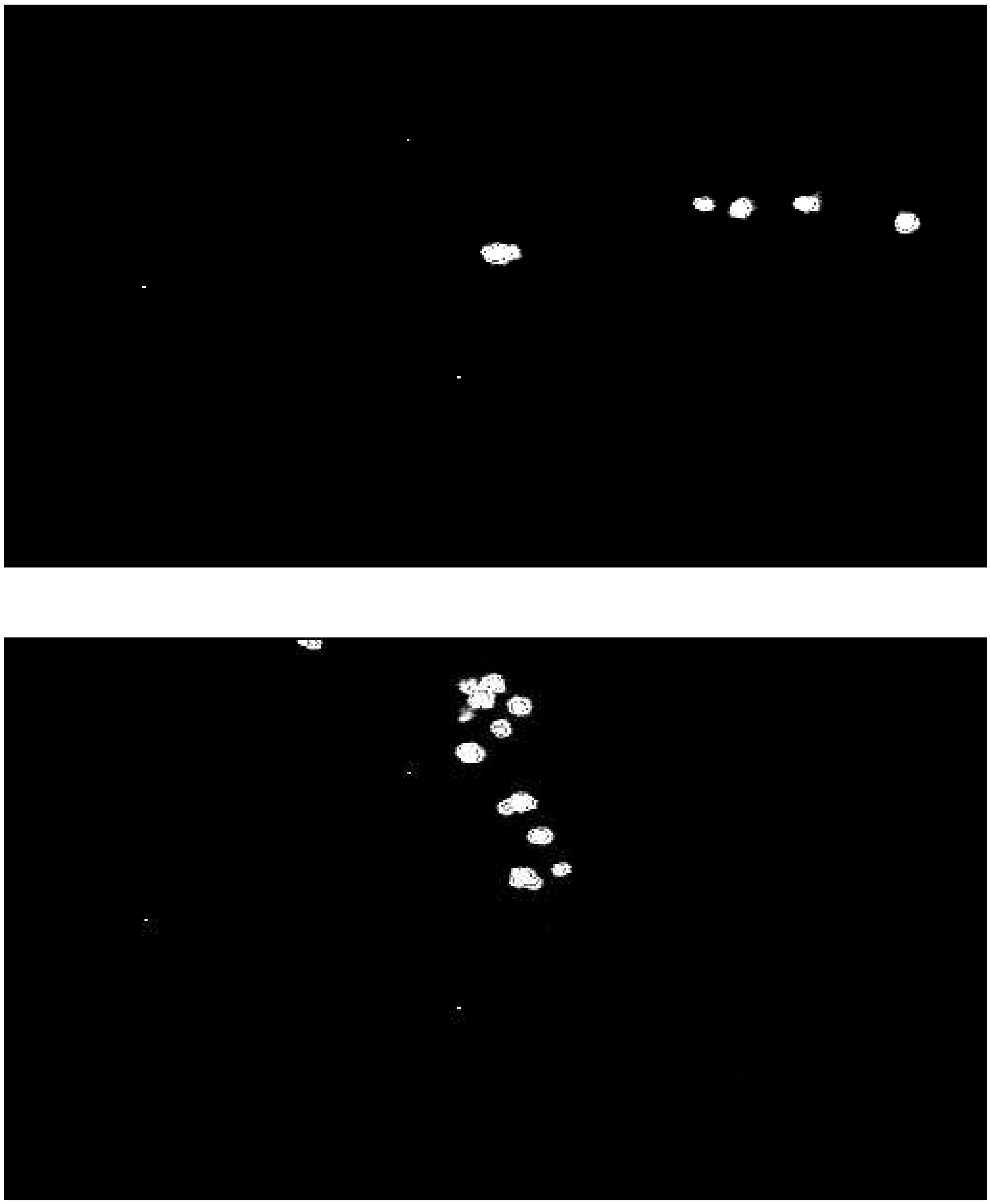

Figure 11: Two examples of picture obtained with CCD camera for the streamer discharge.